

COMPARISON OF SUPERPOSITION MODEL  
WITH FULLY-POPULATED MODEL FOR  
EASTERN SNAKE PLAIN AQUIFER MODEL VERSION 2.2

Idaho Department of Water Resources  
Jennifer Sukow  
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## Table of Contents

INTRODUCTION.....	1
METHODS .....	2
Fully-populated Model.....	2
Numerical Superposition Model .....	3
Simulation of Curtailment .....	4
RESULTS AND DISCUSSION .....	5
SUMMARY AND CONCLUSIONS .....	12
REFERENCES.....	14

## List of Tables

Table 1. Comparison of predicted steady-state responses to curtailment of groundwater irrigation junior to January 1, 1870 .....	6
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## List of Figures

Figure 1. Perched river and drain boundaries removed from superposition version based on average model head from water years 2009 through 2018 .....	4
Figure 2. Predicted steady-state responses at river and spring reaches.....	7
Figure 3. Predicted steady-state responses at river subreaches.....	8
Figure 4. Predicted steady-state responses at Group A and Group B spring subreaches .....	9
Figure 5. Predicted transient responses at river reaches .....	10
Figure 6. Predicted transient responses at spring reaches .....	11

# COMPARISON OF ESPAM2.2 SUPERPOSITION MODEL WITH FULLY-POPULATED MODEL

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## INTRODUCTION

This report provides a comparison of the superposition and fully-populated versions of the Eastern Snake Plain Aquifer Model Version 2.2 (ESPAM2.2). The model versions were compared by performing one of the curtailment simulations presented in Sukow (2021a) with both versions of the model.

The fully-populated version of the model represents all components of aquifer stress, including recharge on irrigated and non-irrigated lands, discharge from groundwater pumping for agricultural and municipal purposes, tributary underflow, perched river seepage, and other components of recharge. The superposition version of the model is a simplified version that can be used to predict the response to a single component of the water budget. This approach simplifies analysis and presentation of results for simulations involving managed recharge, curtailment of groundwater pumping, transfer of water right diversion locations, and mitigation activities.

The numerical superposition version of ESPAM2.2 applies the principle of superposition as described in Reilly et al (1987). The principle of superposition states that the net effect of multiple applied stresses equals the sum of the effects of each individual applied stress. The advantages of superposition are summarized by Reilly et al (1987) as follows.

1. The effects of a specified stress (e.g. groundwater pumping, managed recharge) on the system can be evaluated even if other stresses are unknown.
2. The effects of a change in stress on the system can be evaluated even if the initial conditions are unknown.
3. The effect of one stress on the system can be isolated from the effects of all other stresses on the system.

The principle of superposition is strictly valid only for linear systems. However, Reilly et al (1987) note that because of the power and convenience of the superposition method it is, in practice, commonly applied to mildly nonlinear systems if it can be shown that the resulting error will be acceptably small.

Nonlinearity in ESPAM2.2 may occur if applied stresses cause the aquifer water level in drain or river cells to fall below the drain or river bottom elevation, severing hydraulic connection between the aquifer and the drain or river. The significance of the potential nonlinearity will be dependent on the magnitude and spatial distribution of the applied stress simulated. This report examines the effects of potential sources of nonlinearity on predicted river reach and spring responses for one of the curtailment scenarios presented in Sukow (2021a).

## **METHODS**

The superposition and fully-populated model versions were compared by simulating curtailment of groundwater irrigation rights junior in priority to January 1, 1870. Predicted responses to curtailment were calculated using both the fully-populated model and the superposition version.

### **Fully-populated Model**

Simulations with the fully-populated model were run with the ESPAM2.2 final calibration files (Sukow, 2021b). In the river file, river stage was modified to a constant value equal to the average river stage during the last ten years of the model calibration period (water year 2009 through 2018). Net recharge for the fully-populated model was calculated using average water budget values from water year 2009 through 2018. MKMOD8.2 was used to calculate the average water budget values from the final calibration water budget files.

Determining the hydrologic effects of curtailment using the fully-populated model requires three steps.

1. The fully-populated model was run with the 10-year average water budget and river stage to calculate responses to the average water budget without curtailment.
2. Curtailment was simulated by adding recharge to each model cell containing lands irrigated with junior priority groundwater rights. The recharge added was equivalent to the crop irrigation requirement of the junior groundwater irrigated lands and offsets the withdrawal of water for this use in the fully-populated model. The fully-populated model was run again with the modified stress file to predict responses to the average water budget with curtailment.
3. The results with and without curtailment were differenced to determine the predicted effects of the curtailment.

## Numerical Superposition Model

A numerical superposition version of ESPAM2.2 was created by modifying the ESPAM2.2 final calibration files (Sukow, 2021b) as follows.

1. River cells were evaluated based on modeled conditions using the average water budget from water years 2009 through 2018 (October 2009 through September 2018) to identify perched river cells and dry drain boundaries. Thirty-four perched river cells were removed from the superposition river file and two drain boundaries were removed from the superposition drain boundaries (Figure 1). Because model cells representing spring discharge have two drain boundaries per cell, spring discharge can still be simulated within a model cell at the remaining drain boundary.
2. Drain boundaries were converted to general head boundaries.
3. Starting heads, river stage, and general head boundary stage elevations were set to zero.
4. River bottom elevations were set to -700 feet.

The numerical superposition version requires less input data than the fully-populated model. Only the crop irrigation requirement for the junior groundwater irrigated lands needs to be included in the stress file. The numerical superposition version also requires fewer model runs and less post-processing than the fully-populated model. The hydrologic effects of curtailment can be simulated with one model run, which directly calculates the effects of the curtailment.

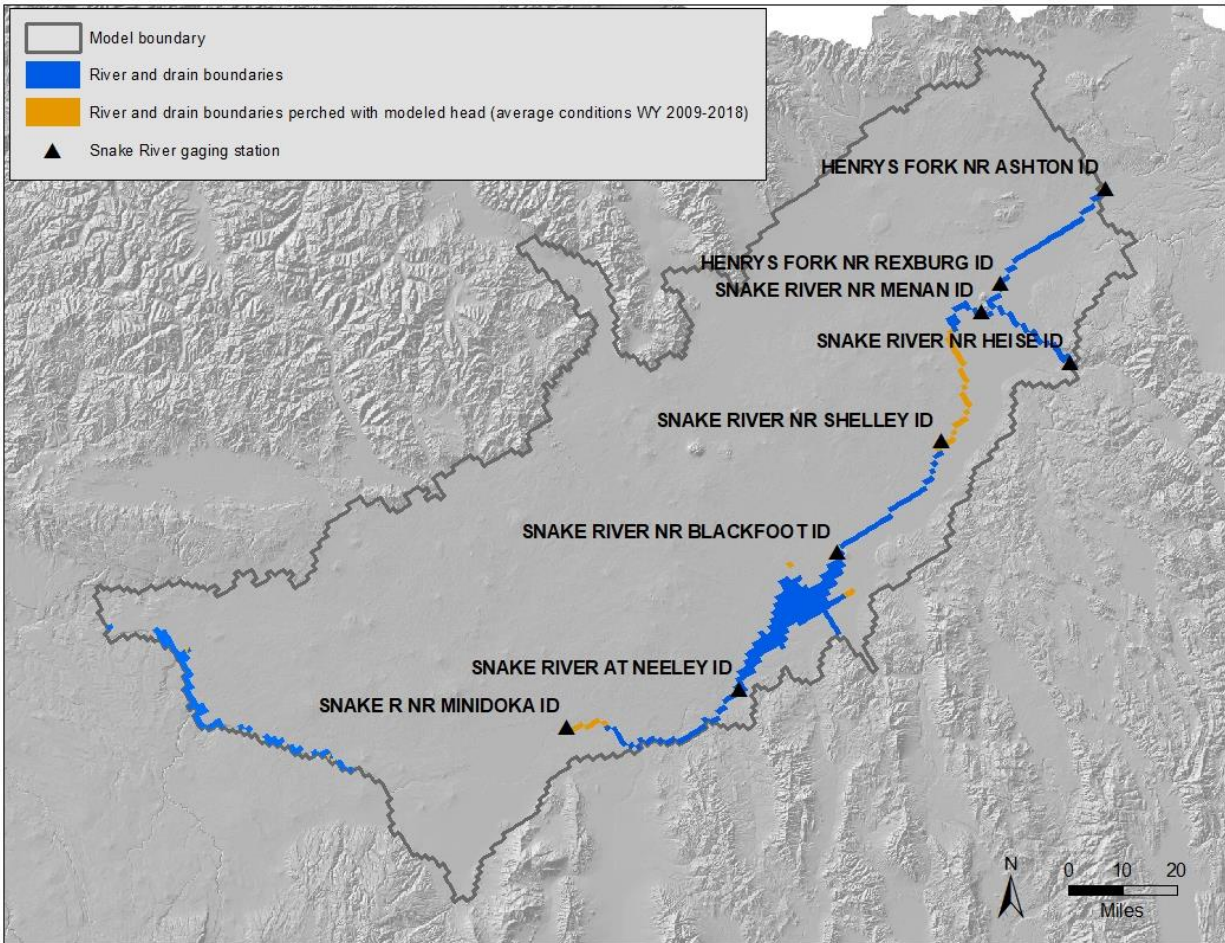


Figure 1. Perched river and drain boundaries removed from superposition version based on average model head from water years 2009 through 2018

### Simulation of Curtailment

Curtailment was simulated by injecting water in each model cell containing lands irrigated with junior priority groundwater rights. The volume of water injected in each model cell was calculated using the Curtailment IAR Tool in the ESPAM2 Recharge Tools<sup>1</sup>. Water right priority dates and point of diversion data used to calculate the fraction of junior priority groundwater irrigated lands were from the 2019 point of diversion (POD) file, which was based on data retrieved from the IDWR water rights database in February 2019.

<sup>1</sup> <https://idwr.idaho.gov/water-data/projects/ESPAM/recharge-tools/>

The most recent irrigated lands data set from year 2015 was used to delineate irrigated areas. Average groundwater fractions were applied to the 2015 irrigated lands data set to delineate areas irrigated by groundwater (Sukow, 2021a).

Average evapotranspiration and precipitation from the last 10 years of the model calibration period (water years 2009 through 2018) were used to calculate the crop irrigation requirement for groundwater irrigated lands. Curtailment of groundwater irrigation throughout the model domain was simulated for water rights junior to January 1, 1870. Steady-state and transient simulations were performed assuming continuous stress based on the average annual consumptive use of groundwater.

## **RESULTS AND DISCUSSION**

Results from the steady-state fully-populated and superposition model simulations are presented in Table 1 and Figure 2 through Figure 4. Results from the transient simulation are shown in Figure 5 and Figure 6.

The superposition model predictions are less than 1.0% different from the fully-populated model predictions for the ESPAM2.2 spring targets, spring reaches and most of the river reaches. The superposition model prediction for the Shelley to near Blackfoot reach is 2% (11 cfs) less than the fully-populated model prediction. The superposition model prediction for the Neeley to Minidoka reach is 11% (12 cfs) less than the fully-populated model prediction. These differences result from the presence of river cells that are perched during the 10-year average condition, but may become hydraulically connected to the aquifer during the simulation as water levels rise in response to a simulated decrease in groundwater pumping (or other increase in net recharge). The fully-populated model is able to respond appropriately to the increase in water levels, but the superposition model cannot because the perched river cells have been converted to model cells without a river boundary. The simulation of curtailment of groundwater irrigation junior to January 1, 1870 models a large change in aquifer stress of 2.7 million acre-feet per year. Differences between superposition and fully-populated model predictions will be smaller for simulations with smaller changes in aquifer stress.

Reach	Predicted response (cfs)		Difference (cfs)	Difference (%)
	Fully-populated model	Superposition model		
Ashton to Rexburg	340	341	0.9	0.27%
Heise to Shelley	314	317	2.8	0.91%
Shelley to near Blackfoot	516	505	-11.1	-2.14%
near Blackfoot to Neeley	1,619	1,633	14.2	0.88%
Neeley to Minidoka	105	93	-11.8	-11.23%
Kimberly to Buhl	268	270	1.6	0.60%
Buhl to Lower Salmon Falls	460	463	2.7	0.58%
Lower Salmon Falls to King Hill	130	131	0.6	0.49%
Total response	3,753	3,753	0.0	0.00%

Table 1. Comparison of predicted steady-state responses to curtailment of groundwater irrigation junior to January 1, 1870



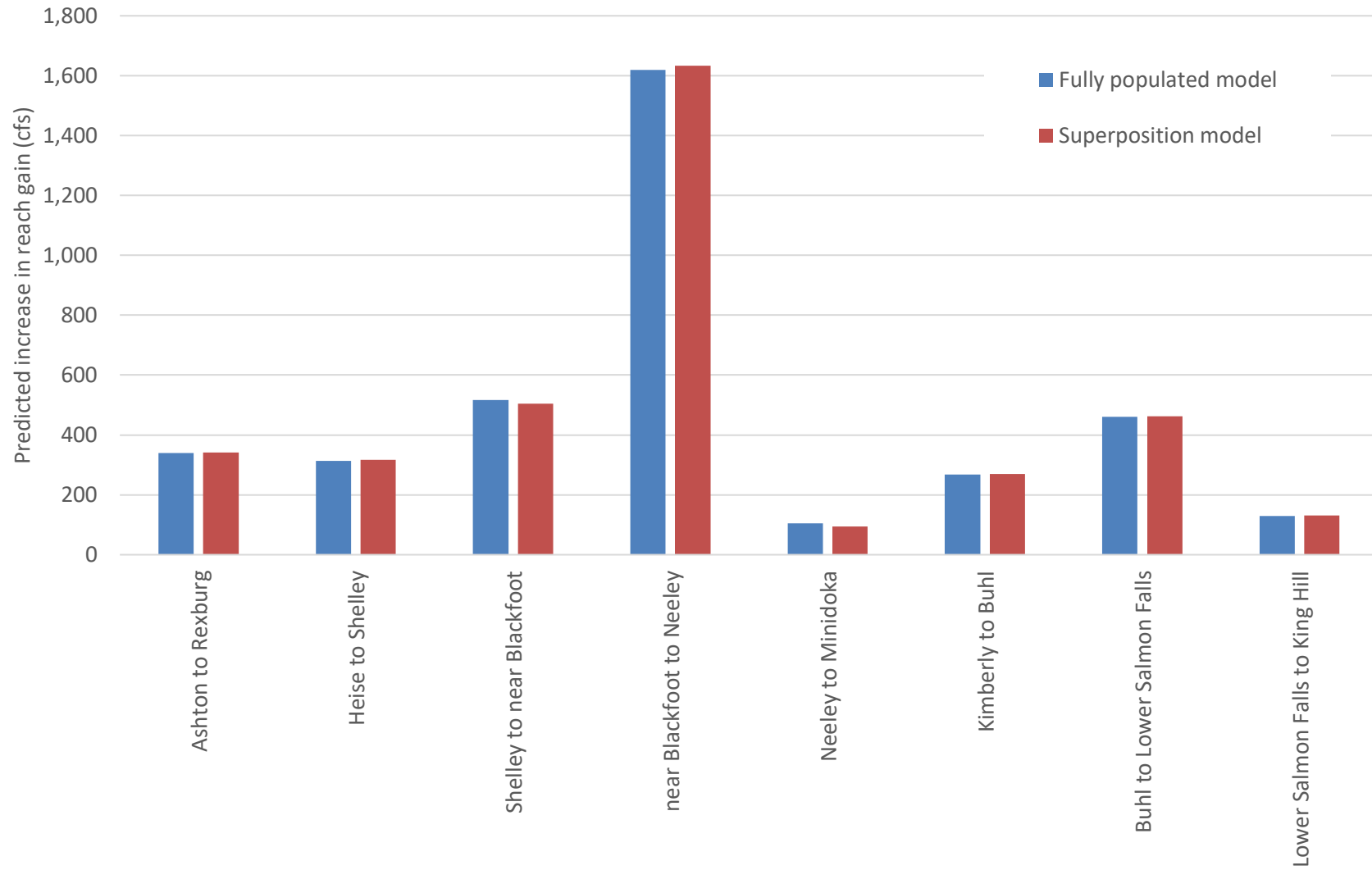


Figure 2. Predicted steady-state responses at river and spring reaches

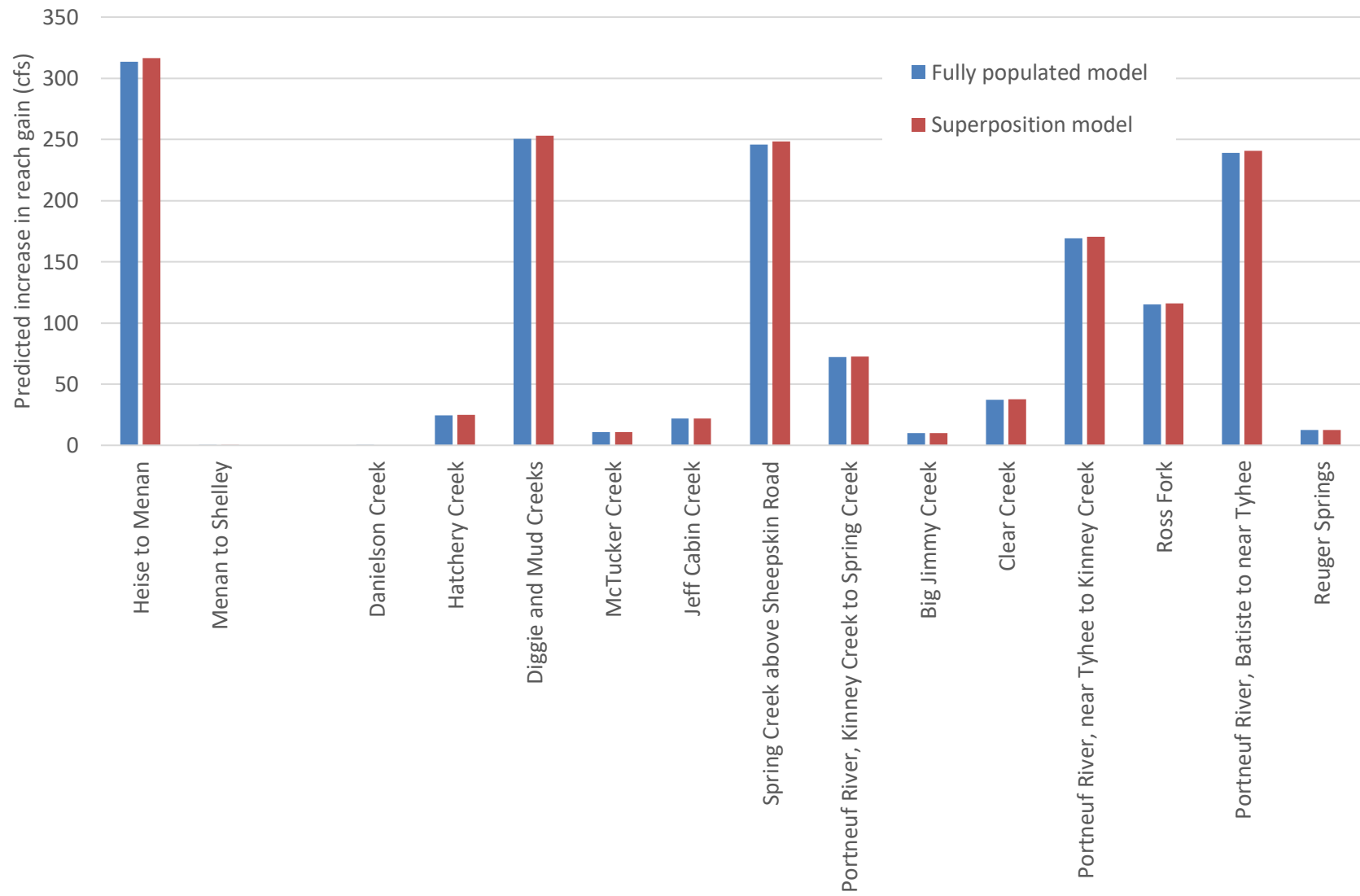


Figure 3. Predicted steady-state responses at river subreaches

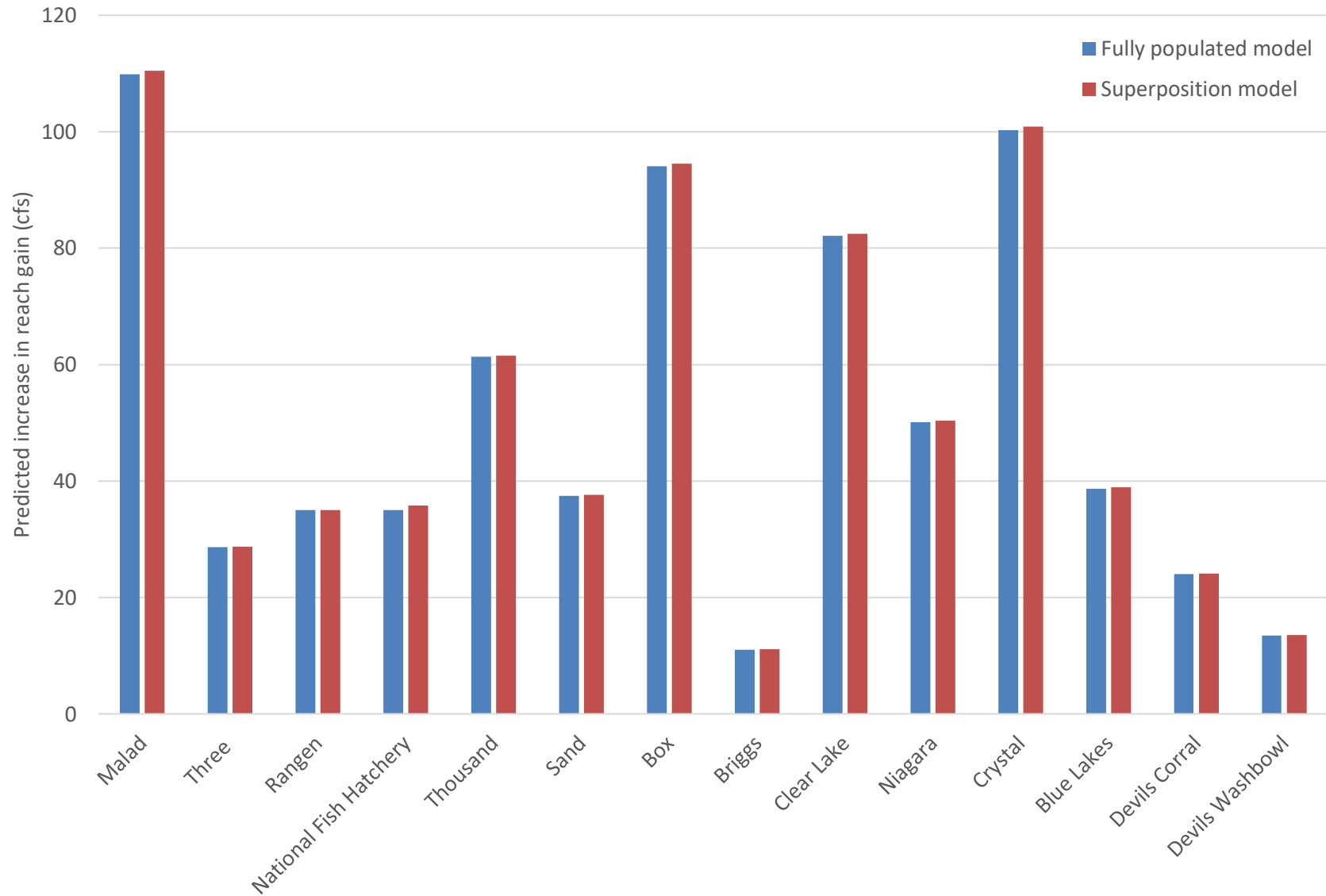


Figure 4. Predicted steady-state responses at Group A and Group B spring subreaches

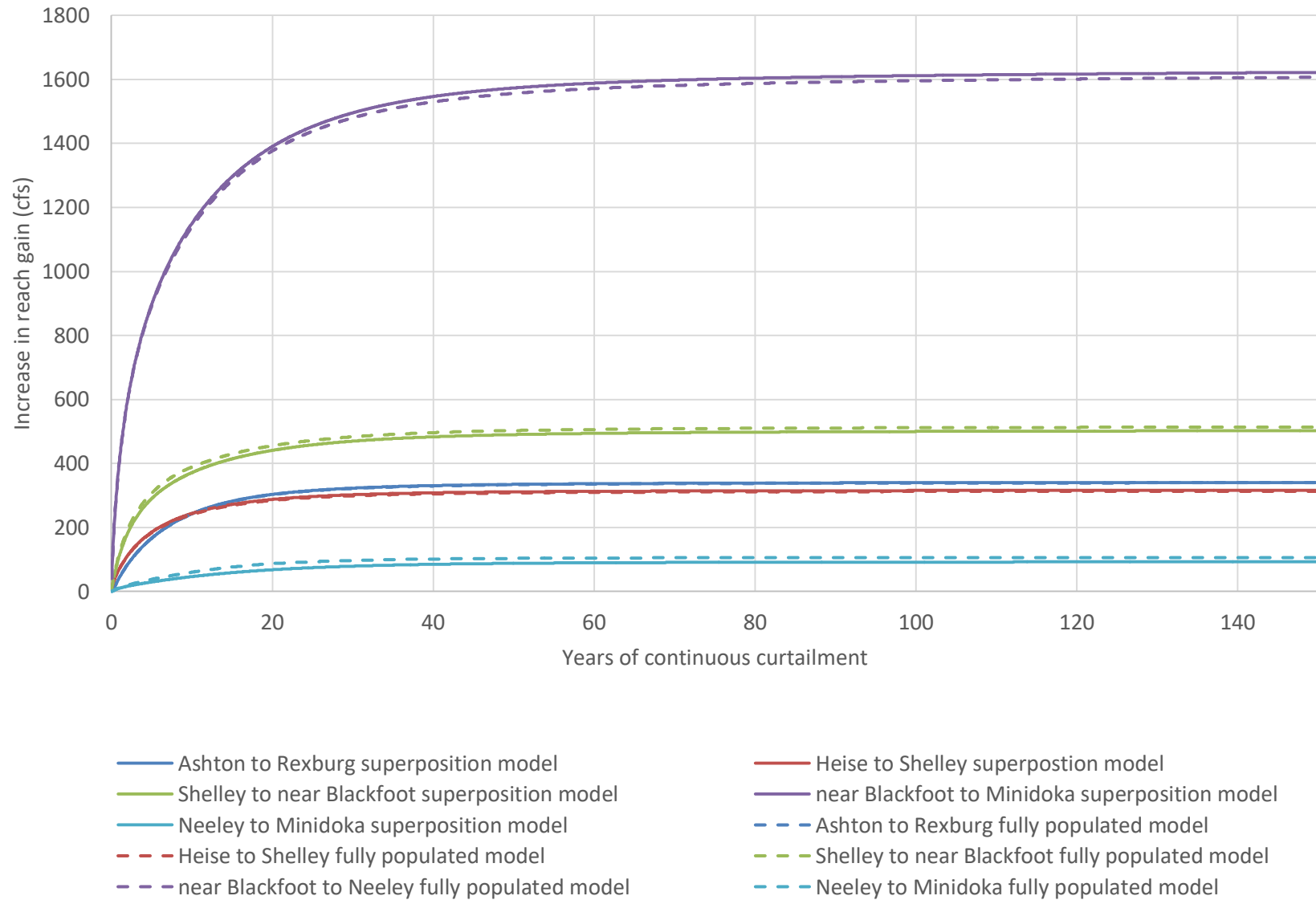


Figure 5. Predicted transient responses at river reaches

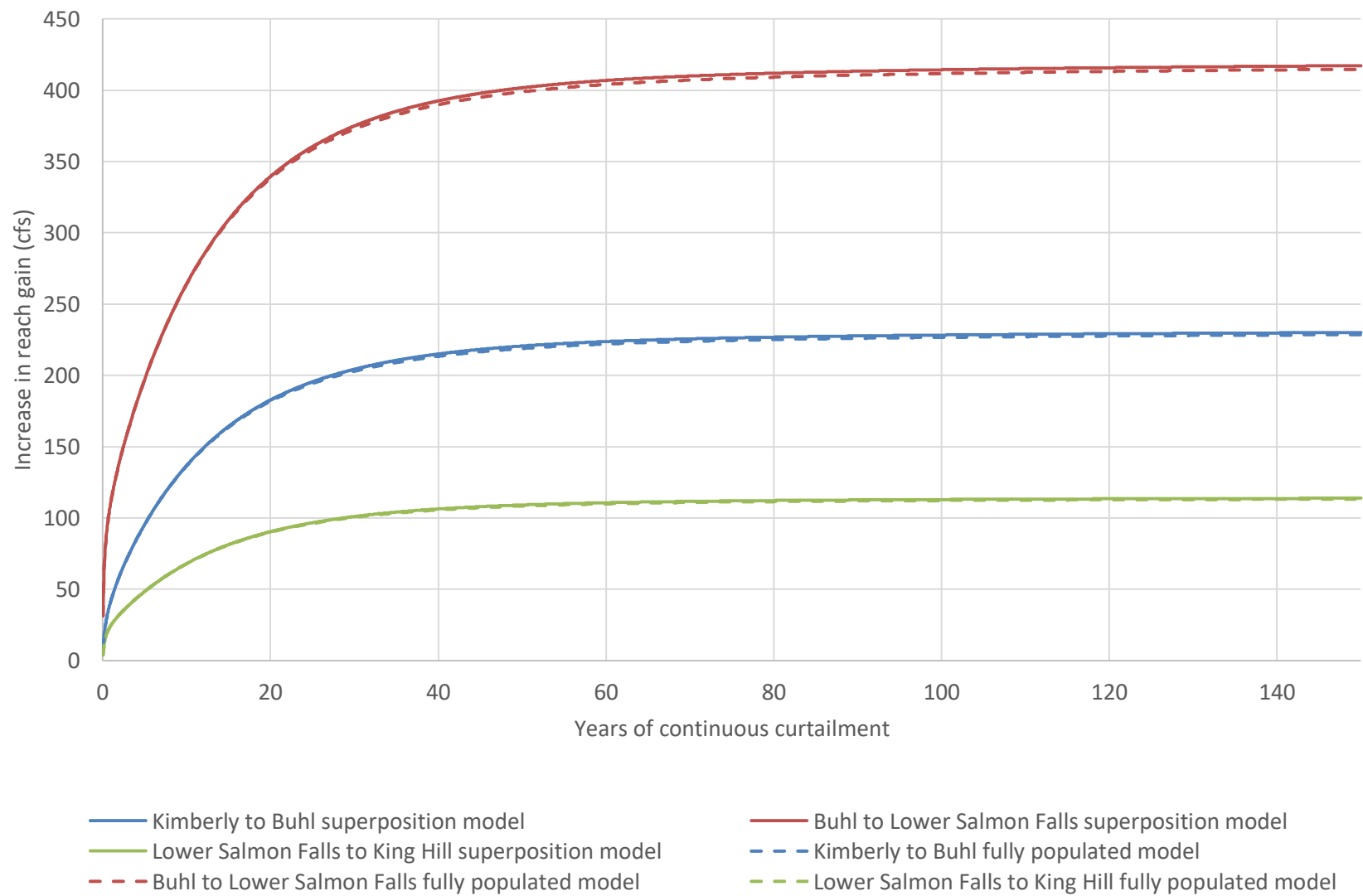


Figure 6. Predicted transient responses at spring reaches

## SUMMARY AND CONCLUSIONS

Differences in responses predicted by the superposition and fully-populated versions of ESPAM2.2 may result from nonlinearity in the model in some circumstances. Potential sources of nonlinearity include aquifer water levels falling below a model drain or river bottom elevation, and aquifer water levels rising above the model river bottom elevation or drain elevation in a river cell or drain boundary that was designated as perched for the superposition version. The removal of perched river cells and drain boundaries in the superposition model was based on average conditions during water years 2009 through 2018, with a net recharge of 6,050 cfs (4.4 million AF/year). Scenarios that significantly change the water budget from those conditions, or place a very large stress at a point location near a drain or river reach, are more likely to cause significant nonlinearity in model simulations.

This report presents a comparison of superposition and fully-populated model results for a scenario curtailing groundwater irrigation junior to January 1, 1870. This scenario simulates a very large (62%) increase in applied stress, increasing the net aquifer recharge by 3,750 cfs (2.7 million AF/year). Even with the large change in applied stress, the superposition model predictions are less than 1% different from the fully-populated model predictions for the ESPAM2.2 spring targets and for most of the river reaches. The superposition model predictions for the Shelley to near Blackfoot and Neeley to Minidoka reaches are approximately 11 cfs (2%) and 12 cfs (11%) less than the respective fully-populated model predictions. Differences in the predictions will be smaller for simulations of smaller changes in model stress.

These results suggest that the superposition version of the model will be acceptable for simulations that have one of the following characteristics.

1. The applied stress is relatively small compared to the fully-populated model water budget. This is typically true for simulations of water right transfers, managed recharge, and mitigation activities. This may also be true for simulations of curtailment, depending on the priority date and areal extent of the curtailment.
2. The applied stress simulates recharge or injection of water, and the magnitude and spatial distribution are comparable to the stress applied in the curtailment

simulation presented in this paper. This is expected to be true of most curtailment scenarios.

For simulations that place a very large localized stress near a drain or river reach, or involve very large changes in the model water budget, use of the superposition model may be inappropriate.

The superposition version of the model requires less input data than the fully-populated version. For example, for a curtailment simulation, only the crop irrigation requirement for the junior groundwater irrigated lands needs to be included in the stress file. The numerical superposition version also requires fewer model runs and less post-processing than the fully-populated model. The hydrologic effects of the curtailment can be simulated with one model run, which directly calculates the effects of the curtailment.

The superposition version of the model is expected to be acceptable for simulation of curtailment of groundwater pumping, managed recharge, most ESPA water right transfers, and mitigation activities including conversions from groundwater to surface water irrigation, the Conservation Reserve Enhancement Program (CREP), and voluntary reductions in irrigation. The fully-populated model may need to be used to simulate a water right transfer if it involves withdrawal of water in close proximity to a drain cell. Other types of simulations that may be proposed in the future will need to be evaluated on a case-by-case basis to determine if use of the superposition model is appropriate.

## REFERENCES

- Reilly, T.E., O.L. Franke, and G.D. Bennett, 1987. *The Principle of Superposition and Its Application in Ground-Water Hydraulics*, U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter B6, 28p., [http://pubs.usgs.gov/twri/twri3-b6/pdf/twri\\_3-B6\\_a.pdf](http://pubs.usgs.gov/twri/twri3-b6/pdf/twri_3-B6_a.pdf).
- Sukow, J., 2019a. *Comparison of Eastern Snake Plain Aquifer Model Version 2.2 with Version 2.1 via the Curtailment Scenario*, Idaho Department of Water Resources, 51 p.
- Sukow, J., 2019b. *Model Calibration Report, Eastern Snake Plain Aquifer Model Version 2.2*, Idaho Department of Water Resources, 181 p.